Impact-Collision Studies

By

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(January 24, 1990)

1. INTRODUCTION

Using a two-stage light-gas gun, whose acceleration ability is up to 6 km/sec for a projectile of a mass less than 1.0 gm, various experiments are performed for studies of impact collision phenomena.

In this article, we report here about four works;

1. Lining materials inside microcraters,
2. (D/T) parameter in microcrater studies,
3. Changes of chemical compositions of ejecta induced by hypervelocity impacts,
4. Foil-stack catcher for Cometary Sample Return Projects.

These results are obtained by collaborations with A. Fujiwara and his co-workers of Kyoto Univ.

2. LINING MATERIALS INSIDE MICROCRATERS[1]

At the time of hypervelocity impact collisions of cosmic dust to targets, it is expected, some amount of residues of the projectile remains inside the microcrater, just like from the meteorite-craters we can gather some Earth's impactites, such as impact-glasses, coacites and shock-metamorphosed breccias.

In our experiments, whose results are shown in the figures of #2, #3 and #4, we will demonstrate the features of the residual materials of the projectile inside the microcraters. We collided a tiny iron-alloy particle (Fe = 94%, Ni = 6%) against Aluminum thick target.

Fig. 1 is the cross-section of an impact-induced microcrater in a metal target, whose diameter (D) and depth (T) are defined as shown.

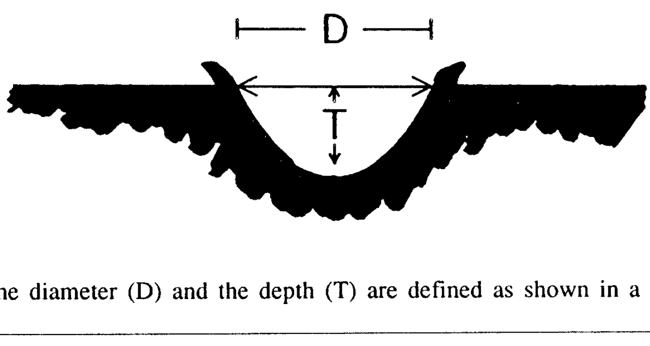

Fig. 1. The diameter (D) and the depth (T) are defined as shown in a metal target.

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Fig. 2. SEM (x 700) A SEM picture of a bottom region

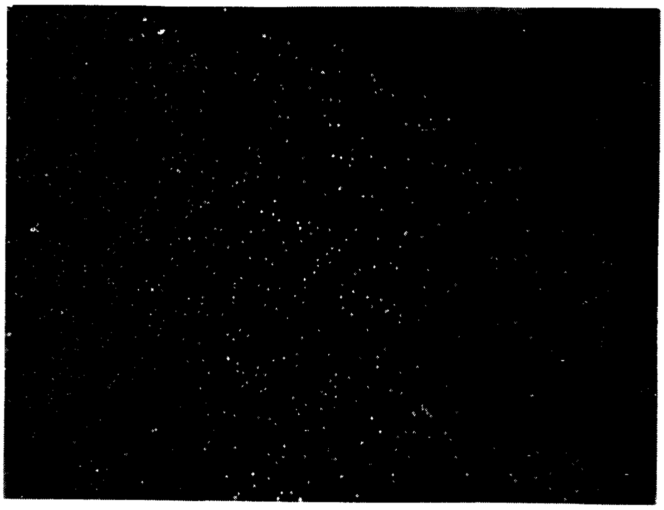

Fig. 3. An XMA distribution pattern of aluminum at the same region

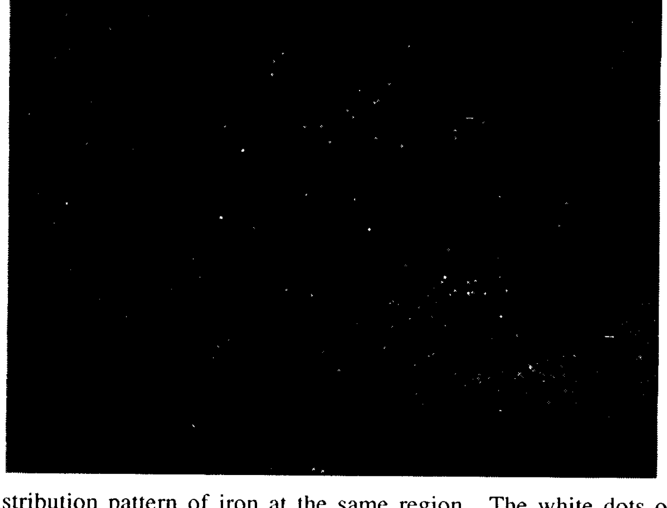

Fig. 4. An XMA distribution pattern of iron at the same region. The white dots occupied the dark area of aluminum distribution.

It is difficult to estimate qualitatively the residual amounts of the projectile materials, which lined up inside the wall of the targets. In the early times of the space developments, it was considered that soft and ductile materials, such as Au or Al, were very suitable target materials for catching the incoming particles. And we expected, in the near future, the INAA method (Instrumental Neutron Activation Analysis) would be improved, so we can measure Fe and Ni components after the decay of neutron-activated, short-lived Aluminum ingot target, which should irradiate gammas strongly but in a short times.

However, this was not so effective method to catch the incoming materials, which are expected to be remained and covered inside the microcrater-walls, because the residual materials were not so much, less than a few percents or more less of the initial projectile mass.

3. (D/T) Parameter In Microcrater Studies[2]

This is a good clue to investigate cosmic dust (projectile) features, such as size, mass, density and chemical compositions, to study microcraters, which are produced on surfaces of bodies of spacecrafts and/or lunar rocks by hypervelocity impacts of cosmic microdebris. In addition, in the early times of the space developing periods of 1970's, it was expected, that a major part of a projectile would be caught by the target materials.

In 1973 Brownlee et al., found two peaks on a diagram of (D/T) and the frequencies, where D is the diameter (inside rim), T is the depth (inside rim) of the microcraters found on the surfaces of the lunar samples. (D/T) = 1.4 and = 1.9 can be seen from the Fig. 5 shown below;

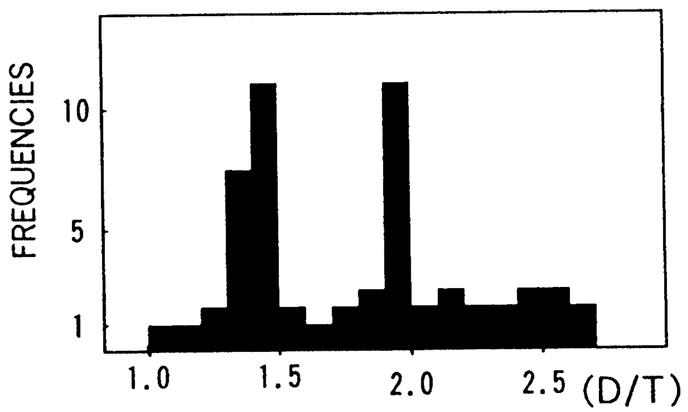

Fig. 5. The distributions of the (D/T) values of the microcraters found on the surfaces of the lunar rocks. (Brownlee et al., 1973).

Smith et al. (1974) and MPI research group in Heidelberg (1975) performed simulation experiments in laboratory and obtained the diagram shown by Fig. 6.

The two peaks produced by iron and glassy projectiles in the simulation experiments are (D/T) = 1.4 for iron and (D/T) = 1.9 for glassy, respectively.

These simulation results are obtained in the velocity range between 4~11 km/sec.

In 1980 Nagel and Fechtig showed the (D/T) values are independent of the impact velocity of the projectiles. By the interesting results we have a possibility to estimate the projectile materials, iron or rocks ?

Detailed investigations about the microcraters remained on the surfaces of the spacecrafts returned after a long time travel in space will show us, the abundance ratio of (iron/silicate) dusts in space. This promises the most simple and non-sophisticated detection design for chemical composition analysis of the cosmic dust in space. Yamakoshi and Fujiwara (1986) added the results and confirmed the independences of the parameters of (D/T) of the velocities of the projectiles, which are shown below in Fig. 7.

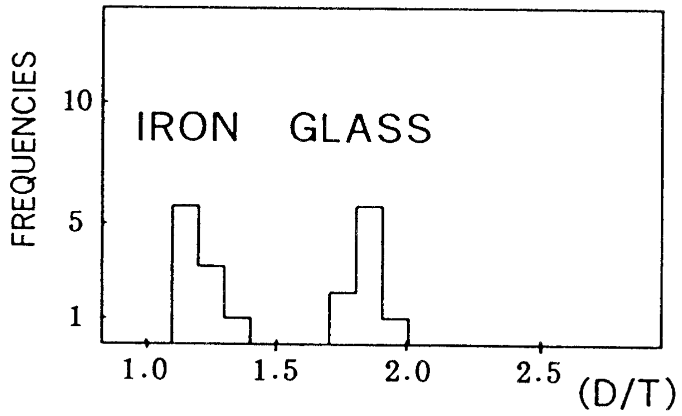

Fig. 6. (D/T) distributions obtained by simulation experiments using iron and glassy projectiles with feldspar targets

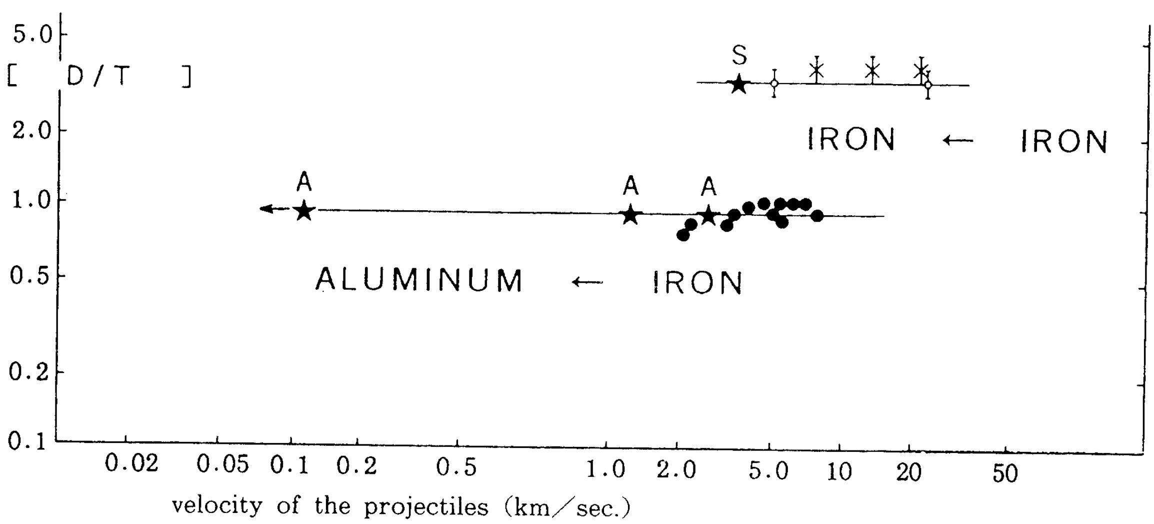

Fig. 7. The diagram of (D/T) values and the velocities of the projectiles; [MPI in Heidelberg; ∘ = iron, × = carbon projectiles to stainless steel targets and • = iron projectiles to aluminum targets] and [ours; ★S = stainless steel projectile to stainless steel target and ★A = Fe (94%)–Ni (6%) projectiles to aluminum targets].

It is very interesting, that (D/T) is independent of the velocity of the projectile in wide range and dependent on the combination of the materials of the projectile and target only.

The fundamental physical process of the microcrater formation and (D/T) ratio determinations in various combinations of materials must be studied quickly in future.

4. Changes Of Chemical And Isotopic Compositions Of Ejecta Induced By Hypervelocity Impacts[3]

In order to study changes of chemical compositions of ejecta scattered from dust-dust and dust-meteorite collisions in space, two laboratory hypervelocity impact experiments by two-stage light gas gun were performed. In this work, although we measured only changes of chemical compositions of ejecta, we will do some experiments to study the changes of isotopic compositions in ejects in the near future.

Changes of chemical compositions including noble gas contents and also mineral phases in shocked chondrites and iron meteorites have been studied from a point of view of collision-induced metamorphism of cosmic matter in space.

In this work, in order to research changes of chemical compositions of ejecta scattered from dust-dust and dust-meteorite collisions in space, two laboratory simulation experiments by a two-stage light gas gun were performed.

In order to find changes of the chemical compositions in ejecta easily, as a common material a stainless steel, SUS 304, was used for both projectiles and targets, because SUS 304 steel is an industrial product, of which we can expect a good homogeneity of the physical and chemical characteristics and also it was thought to be resistant to oxidization in the impact processes.

To avoid oxidization of the materials during the coarse of impact, the impact chamber was kept in vacuum (~0.1 Torr.). However, this vacuum condition was not adequate enough to protect the smallest grains of the ejecta against the oxidization.

A large amount of styrofoam blocks and magazine papers packed in the impact chamber caught the ejected fragments without so much deformation and losses.

The chemical composition of the material was similar to those of iron meteorites and/or the metal phases in ordinary chondrites. And they were analyzed using the instrumental neutron activation analysis (INAA) and the homogeneity of the raw material (SUS 304) used in this work also checked with an X-ray micrometer. The projectiles were fired by a two stage light gas gun, which can accelerate a bullet of ~ 1 gram up to 6 km/sec. 0.1 Torr. of air pressure was kept in the impact-chamber with a rotary vacuum pump.

In the first run, a cylindrical projectile (4 mm diameter × 2.15 mm length) of mass 0.209 g, which was mounted in front of a polyethylene sabot (7 mm diameter × 10 mm length) of mass 0.350 g was impacted normally against the facial center of a cylindrical target (6 mm × 2.7 mm length) of mass 0.612 g. The velocity of the projectile was 3.6 km/sec. The energy density (total kinetic energy of the projectile/mass of the target) was 2.21×10^{10} (erg/gm).

In the second run, a cylindrical projectile (4 mm diameter × 1.6 mm length) of mass 0.152 g, which was mounted on a nylon sabot (7 mm diameter × 9 mm length) of mass

0.304 g, struck normally at the facial center of a cubic target (50 mm × 50 mm, 30 mm length) of mass 594 g. The velocity of the projectile was 3.86 km/s. The produced crater on the target was 16 mm in diameter (inside rim) and 4.5 mm in depth (excluding rim height). The energy density was 1.9 $\times 10^7$ (erg/gm).

The chemical compositions of the ejecta and the raw material were determined by INAA with TRIGA II reactor. The raw material (SUS 304) was checked with a reference sample (Canyon Diablo) of homogeneous form (Nogami et al., 1980) and Cr an Sb were obtained with JB-1 glass reference. And we could obtain the chemical composition of the SUS 304 as [Fe] = 75.6%, [Ni] = 6.35%, [Co] 0.152%, [Cr] = 17.7% and [Sb] = 0.33 ppm in weight. The inhomogeneity of chemical compositions in raw material was checked for seven chips cut from the raw material, whose data were coincided within ±5%. And also SUS 304 was checked by X ray microanalysis; the ratios of K-X ray intensities of Cr to Fe and Ni to Fe were obtained from more than 40 spots on the surfaces of the SUS 304 (each spot size; 40×300 μm) as 0.4283 ±0.0131 for (Cr/Fe) and 0.104 ±0.00252 for (Ni/Fe).

4.1 RUN 1; The Grain to Grain Collision

In the experiment of Run 1, a catastrophic fragmentation of the target and the projectile occurred. The scattered fragments were gathered from the styrofoam and magazine papers, which were packed in the impact-chamber. The styrofoam was dissolved with toluene and the lodged ejecta were collected. The small fragments lodged into magazine papers were taken carefully by turning over the pages. However, the total weight of the scattered fragments, which were recovered from the packing material, amounted at most to only 20% of the total amount of the target and projectile. Therefore, a size distribution of the scattered debris could not be obtained. No spherical grain was found in the collected debris.

The chemical compositions of the collected fragments were determined by INAA and the data were normalized by those of the raw materials, which are shown in Fig. 8 and 9.

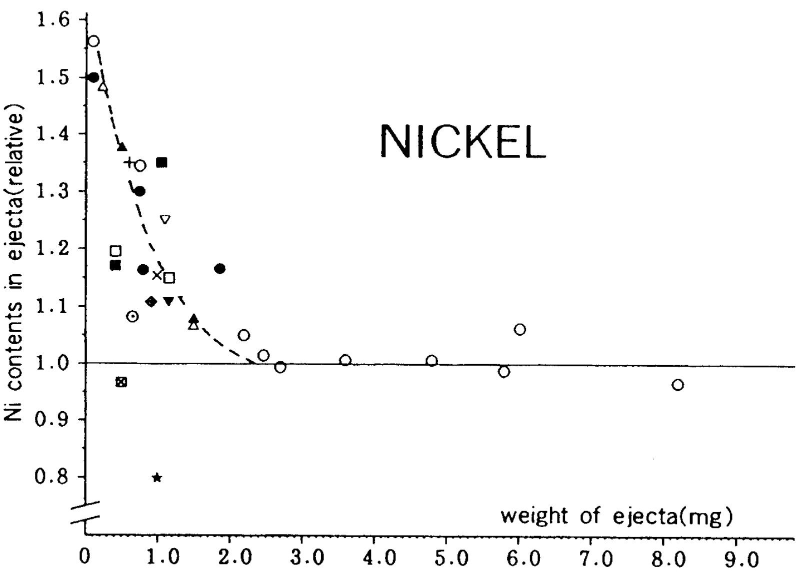

Fig. 8. Ni and Co contents in the fragments of ejecta, relative to those of the raw material, obtained in RUN 1. Various symbols are used for identification of the respective sample fiin the figure.

In Fig. 10 and 11 the behaviors of Cr and Fe contents are shown. The Cr contents are nearly constant throughout the mass region except for a few cases. The Fe contents are widely scattered, however, in general Fe is depleted in all cases.

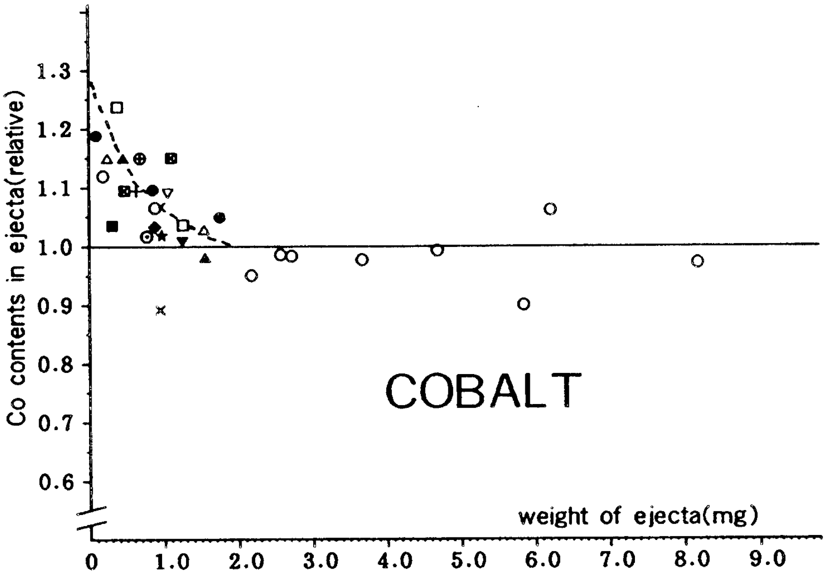

Fig. 9. Ni and Co contents in the fragments of ejecta, relative to those of the raw material, obtained in RUN 1. Various symbols are used for identification of the respective sample in the figure.

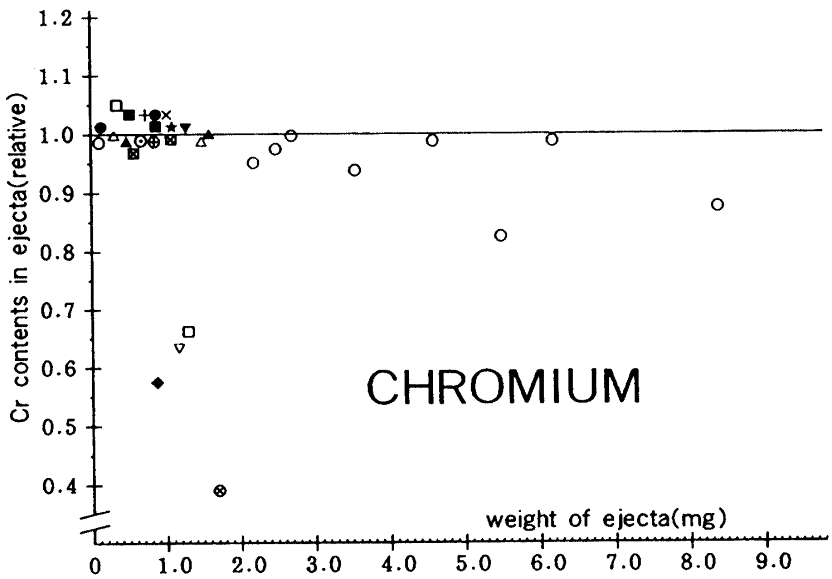

Fig. 10. The behaviors of Cr and Fe contents in the ejecta.

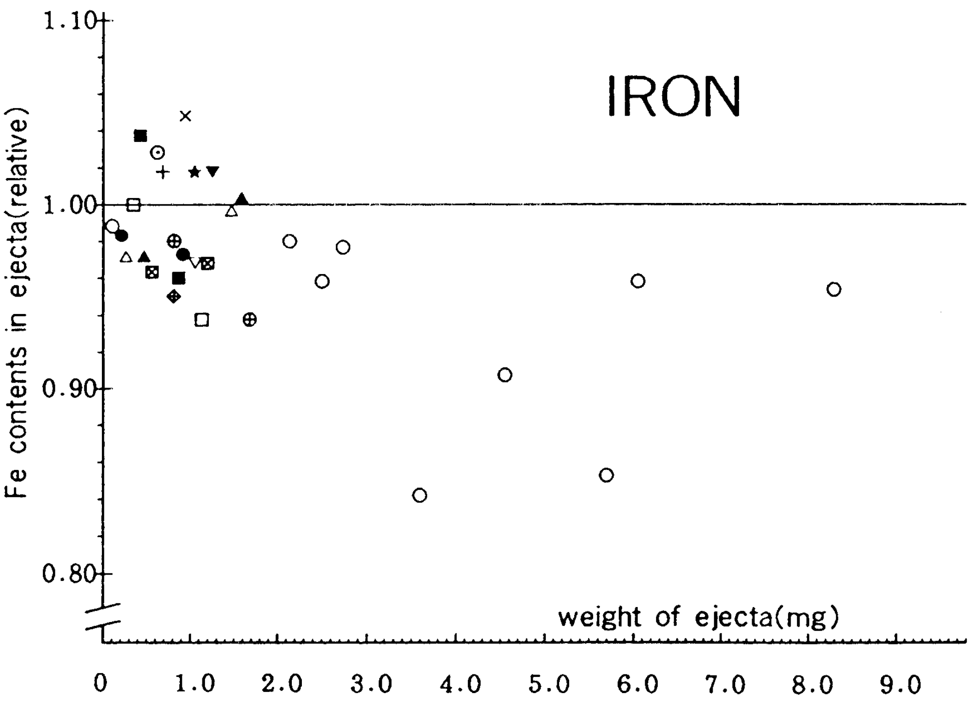

Fig. 11. The behaviors of Cr and Fe contents in the ejecta.

4.2 RUN 2; The Grain to Large Body Collision

The [diameter/depth] ratio of the crater left on the target was 3.6 and also the mass ratio of the ejecta to the projectile was 2.7. In this run, also no spherical grain was found in the collected ejecta. Many fragments has twisted shapes, on which a special pattern, just like a rifle mark, was observed. This pattern originated from the target surface, which was processed by a milling cutter. Some of the fragments looked all burned up and had changed to blue-violet colour. Over 90% of the ejected mass were recovered, which was the amount of the projectile plus the ejected mass from the target crater.

The mass distribution of the ejecta is shown in Fig. 12. The distribution of elemental compositions of the smaller ejecta were determined also by INAA.

The chemical compositions of the ejecta is shown in Fig. 13. The contents of Fe, Ni, Co and Cr in the ejecta normalized with those of the raw material.

In Run 1, the target was so small-scaled, that it was broken and scattered around, while in Run 2, only cratering occurred in the target block. It could be explained, that the former energy density was higher than that of the latter ones in three orders of magnitude (Fujiwara et al., 1980).

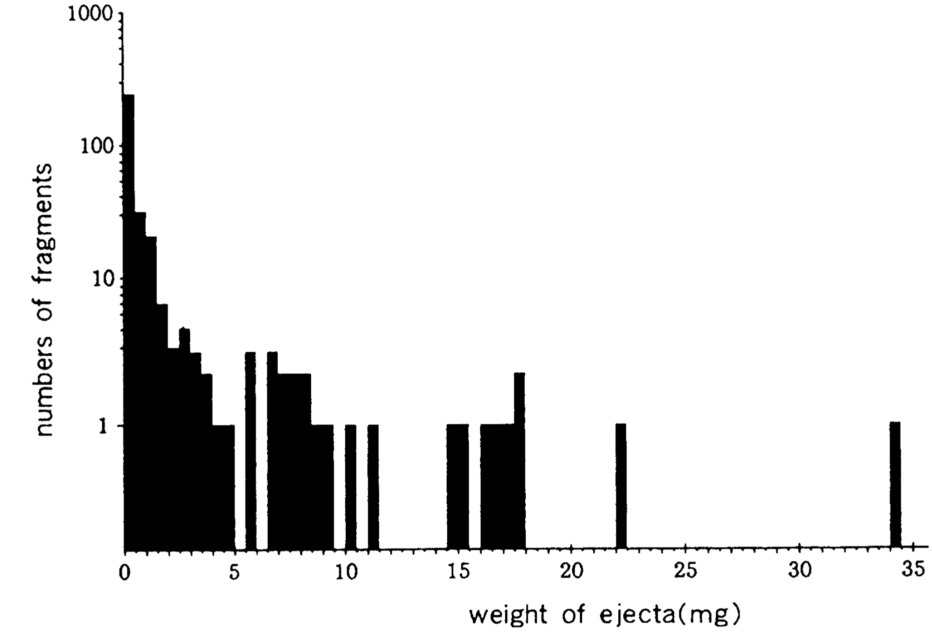

Fig. 12. Mass distribution of the ejecta in RUN 2.

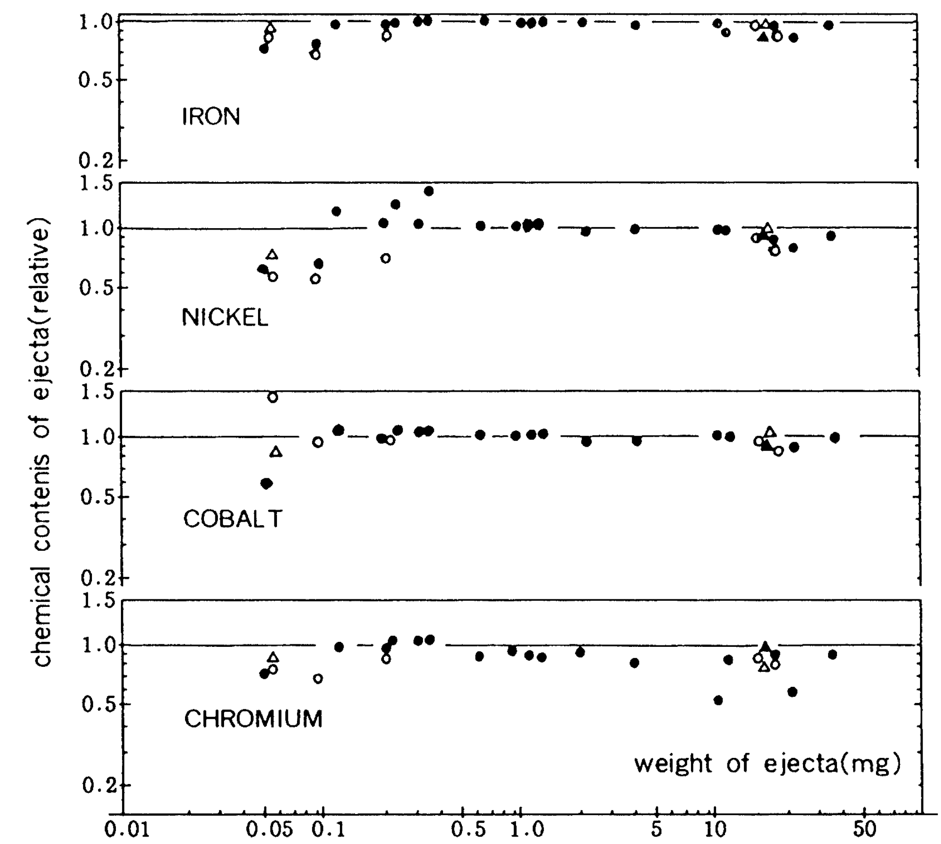

Fig. 13. Fe (upper), Ni, Co and Cr (lower) contents in the fragments of ejecta, normalized with those of the raw material. Various symbols are used for identification of the respective data in the figures.

The Rankine-Hugoniot one-dimensional calculation gives the originated pressure (P) and the peak temperature (T) at the shock front of the impact;

Run 1; P = 1.02 Mbars, T = 1600 K,
and Run 2; P = 1.12 Mbars, T = 1850 K in these experiments.

The reaction time duration is indeed so short, however, the given pressure is so higher (just three orders of magnitude) than that produced by the hydrostatic pressurizing techniques. The shock loading duration times were estimated as 0.67 μsec. for Run 1 and 0.69 μsec. for Run 2.

In these experiments the enrichment of Ni and Co components occurred largely in smaller fragments, which might have been the affect of the strong shock and we are restricted in the small volume adjacent to the impact site. Despite the poor statistics of the radiation counting, the depletion of Sb contents also occurred in the smaller fragments in Run 2. In these fragments we could find an inverse correlation between Ni and Sb, in which Co contents were also enriched.

Any distinct casual and sophisticated relation could not be obtained here. However, the enrichments of Ni and Co might be caused by the depletion of the most abundant component, Fe, in the ejecta. In the behavior of Cr contents in the ejecta, no distinct size dependence was seen in both experiments.

The results obtained here suggest the possibilities of the enrichment or depletion of chemical components in the ejecta during the dust-dust and also dust-meteorite impact phenomena in space. In this work, we could not examine the changes of isotopic fractionations due to the hypervelocity impact phenomena.

However, in order to understand exactly the enrichment and depletion of the elemental compositions in the ejecta, further impact examinations on various materials are necessary, because our results were made only with some special sets of experimental conditions; materials, target sizes, velocities of the projectiles and vacuum conditions.

Many problems are remained as unsolved, some changes will happen in the isotopic compositions caused by hypervelocity impacts; cosmogenic nuclides in cosmic targets and Eu or Yb anomalies in REE patterns in cosmic matter, etc.

5. Foil Stack Catcher For Cometary Sample Return Projects[4]

We made some interesting laboratory experiments for cometary dust collection. In Kyoto University, Fujiwara has constructed a good two-stage, light gas gun, whose highest speed attains up to 6 km/sec ($\leq$ 1 gm of projectile).

In the first experiment of this study, we prepared an Al-foil stack target. 20 sheets of Al foils were folded. The thickness of each foil was 15 microns, and stapled at three points in 120° opening angle for each. Finally 10 stacks were fixed at a distance of 5 mm for each and the final stopper was Mg plate, whose thickness was 5 mm. The stacks and the stopper were fixed at a ring-frame using a set of fringe.

The projectiles were basalt grains, whose weights were about 0.1 gm and mounted on nylon sabots. The experiments were carried out in a chamber, which was kept in vacuum by a rotary pump. A series of this experiments were performed, in which the projectile-speed was about 1 km/sec. for each.

After the impacts, the projectiles were broken largely by the Al-foil stacks. However, the final Mg stopper plates were scarcely scrashed.

And about 78% of the initial projectile mass were recovered from the Al stack house.

The foils were broken so largely, as the speed of the projectile fell down.

In this experiments, the shock-waves were run away into two dimensional directions at right angle on the respective foil-surfaces.

As a similar phenomena, this event looks just like heavy ionized particles, which is going thru materials, the particle goes the slower, its energyloss rate becomes the larger.

Fig. 14 shows the face-pictures of the first [1~20] and the final [180~200] stack after the penetration.

The broken holes became bigger and bigger and at the almost final end stage the broken holes were the extremely large. However, the final stopper, Mg plate, was kept only as scarcely damaged.

The another experiment was carried out for comparative demonstration (Fig. 15).

The target was Al-plate, whose thickness was 3.0 mm. It was just the same thickness of aluminum used in a previous foil-stack experiment. The projectile speed and other conditions were kept as the same as those of the foil-stack experiment.

However, the projectile penetrated the Al plate with no trouble. And also in the final stopper, Mg plate, a micro-crater was created, whose depth was just 6 mm. And the crater (Mg), the target-hole (Al) and the projectile (Fe, Ni) materials were ejected away to the opposite directions.

The thin foils were broken foil by foil, more and more largely into two directions, which were normal to the direction of the incoming projectile.

Fig. 14. The face-pictures of the first and the final foil-stacks after the penetration of the projectile.

From those experiments, Al-foil stack dust catcher is one of the most effective mechanism for slowing-down of the projectile.

The stack of many thin Al-foils will be good "shock-absorber". Therefore, it will be useful also for the wall-structure of the space-station and/or lunar bases against hypervelocity incoming cosmic debris.

Fig. 15. The pictures of the penetrated aluminum plate of 3.0 m/m in thickness (right) and the damaged Mg stopper (microcrater).

References

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